Designing Mission Operations for the Gravity Recovery and Interior Laboratory Mission

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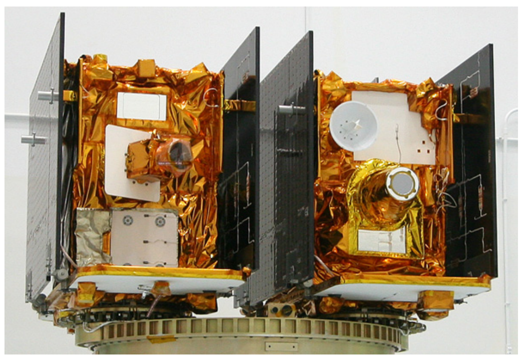
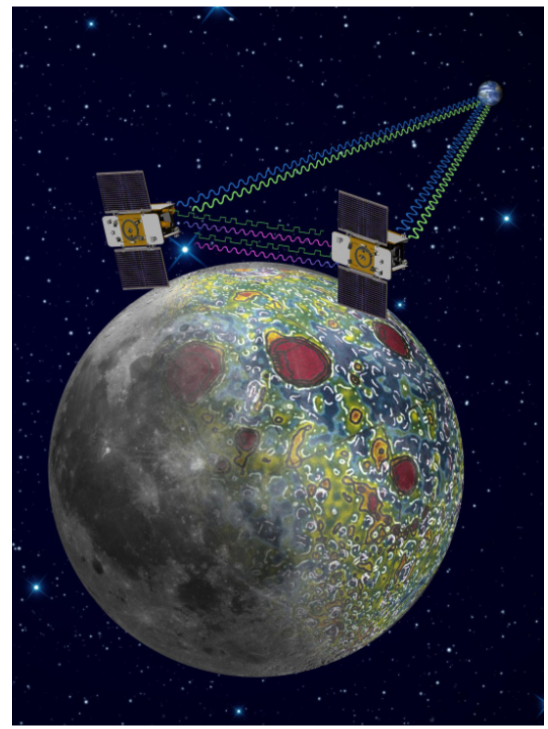
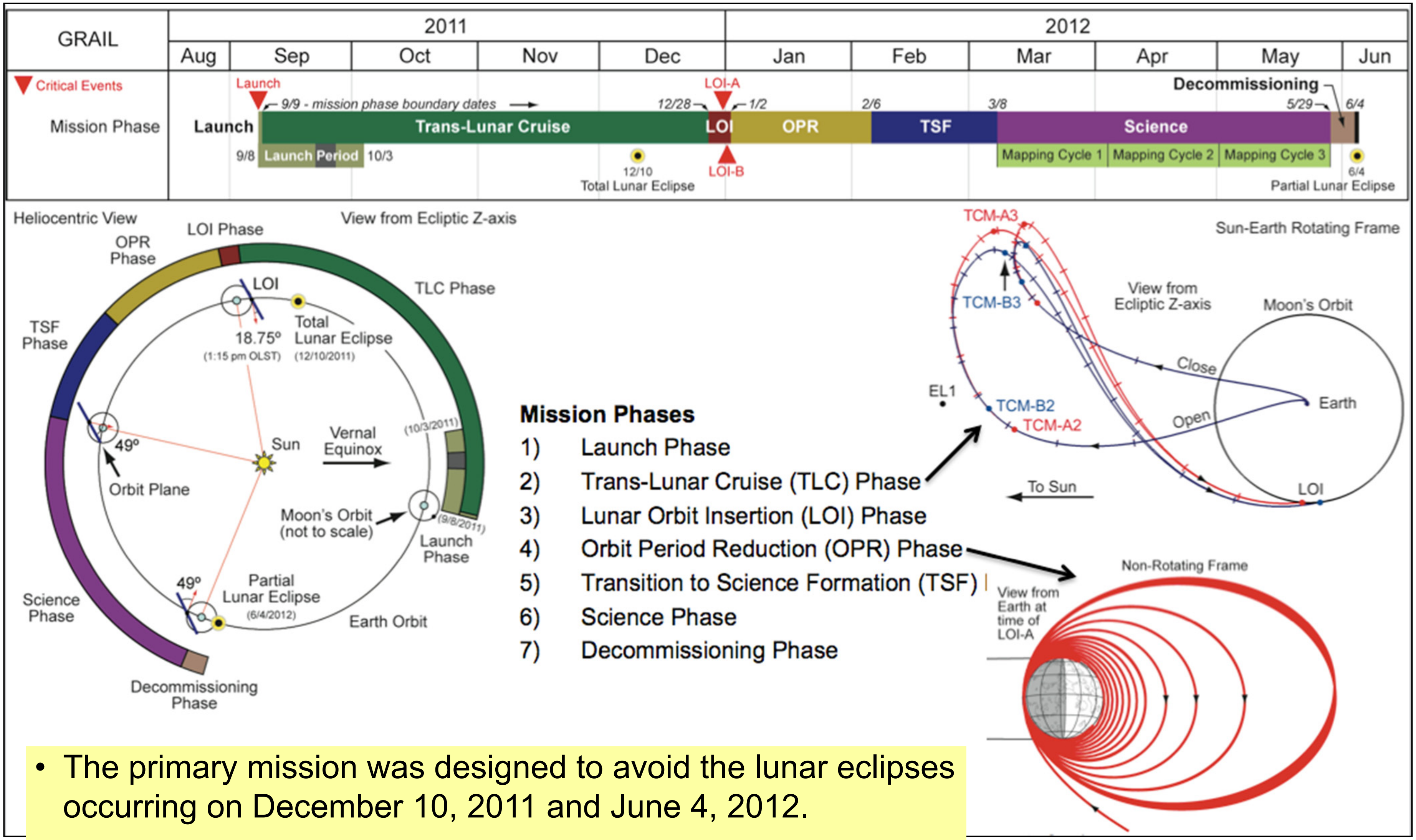
Introduction

- The Gravity Recovery and Interior Laboratory (GRAIL) mission has placed two orbiters in a low altitude polar orbit around the moon to study its internal structure.
  - Precisely measure distance between orbiters and their position around the moon via DSN tracking.
  - Science team combines information to produce gravity field map of unprecedented accuracy.
- GRAIL mission to the Moon offered unique challenges to operations:
  - Operate twin-orbiters in parallel
  - Numerous maneuvers (33 baselined)
  - Short, compact mission with six unique phases
  - Detailed contingency planning required
- Operations design leveraged off of high heritage multi-mission operations developed by JPL and Lockheed Martin.





Mission Overview

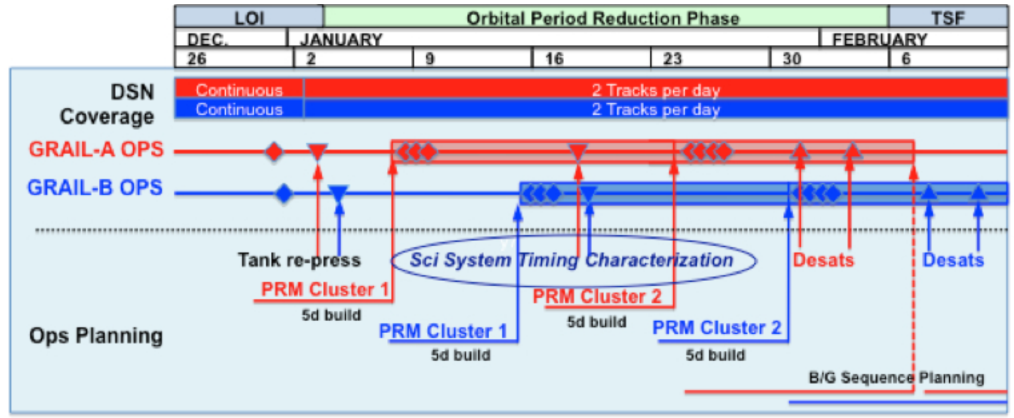


- The primary mission was designed to avoid the lunar eclipses occurring on December 10, 2011 and June 4, 2012.
- Launch & TLC phases designed to target GR-A LOI on December 31, 2011, and GR-B on January 1, 2012.0

Mission Overview – OPR, TSF, & Science Phases

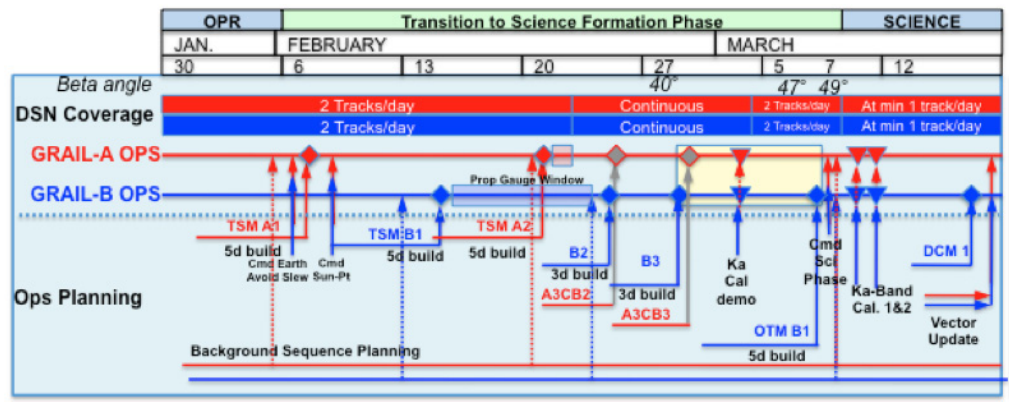
ORBITAL PERIOD REDUCTION (OPR)

- 7 Period Reduction Maneuvers (PRMs) per orbiter, divided into two clusters.
- Reduces 11.5 hour orbit to less than 2 hours.
- Utilized 5 day maneuver planning timeline.
- Background (housekeeping) sequence merged with maneuver sequence.



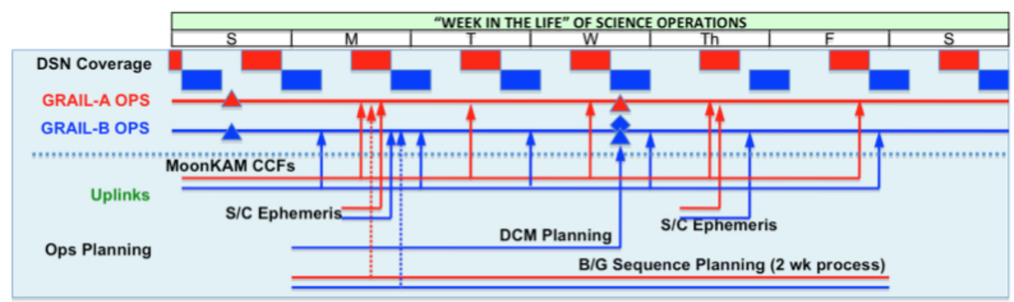
TRANSITION TO SCIENCE FORMATION (TSF)

- Orbiters no longer flown independently.
- 5 Transition-to-Science Maneuvers (TSMs) place GRAIL into science formation with GR-B leading GR-A.
- Planned on tighter 3-day timelines, with contingency maneuvers on other orbiter.
- Transitions from sun-point to orbiter-point.



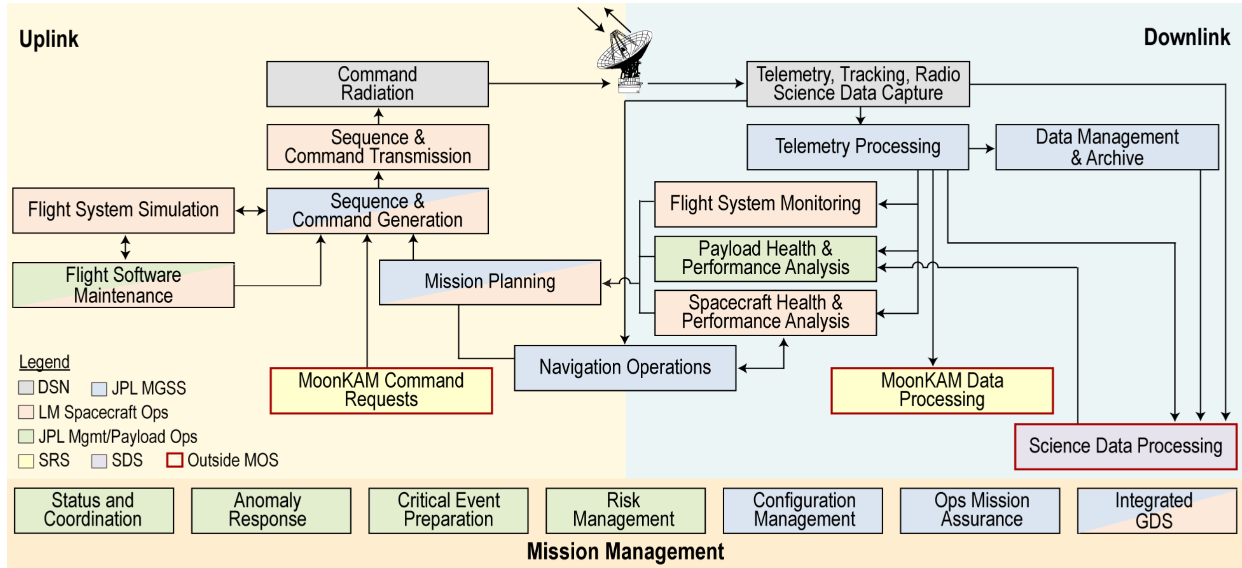
SCIENCE

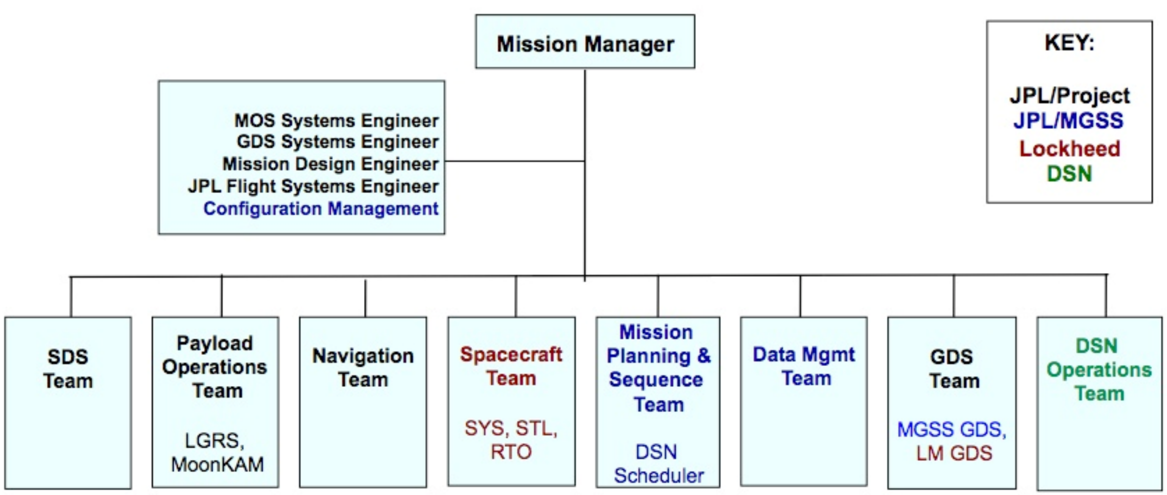
- Daily DSN tracking for both S-band Science & EPO data, and X-band Radio Science Beacon.
- Momentum “desats” scheduled at near poles.
- Twice weekly ephemeris updates for pointing.
- Delta-V Correction Maneuvers (DCMs) not needed.



MOS Operational View

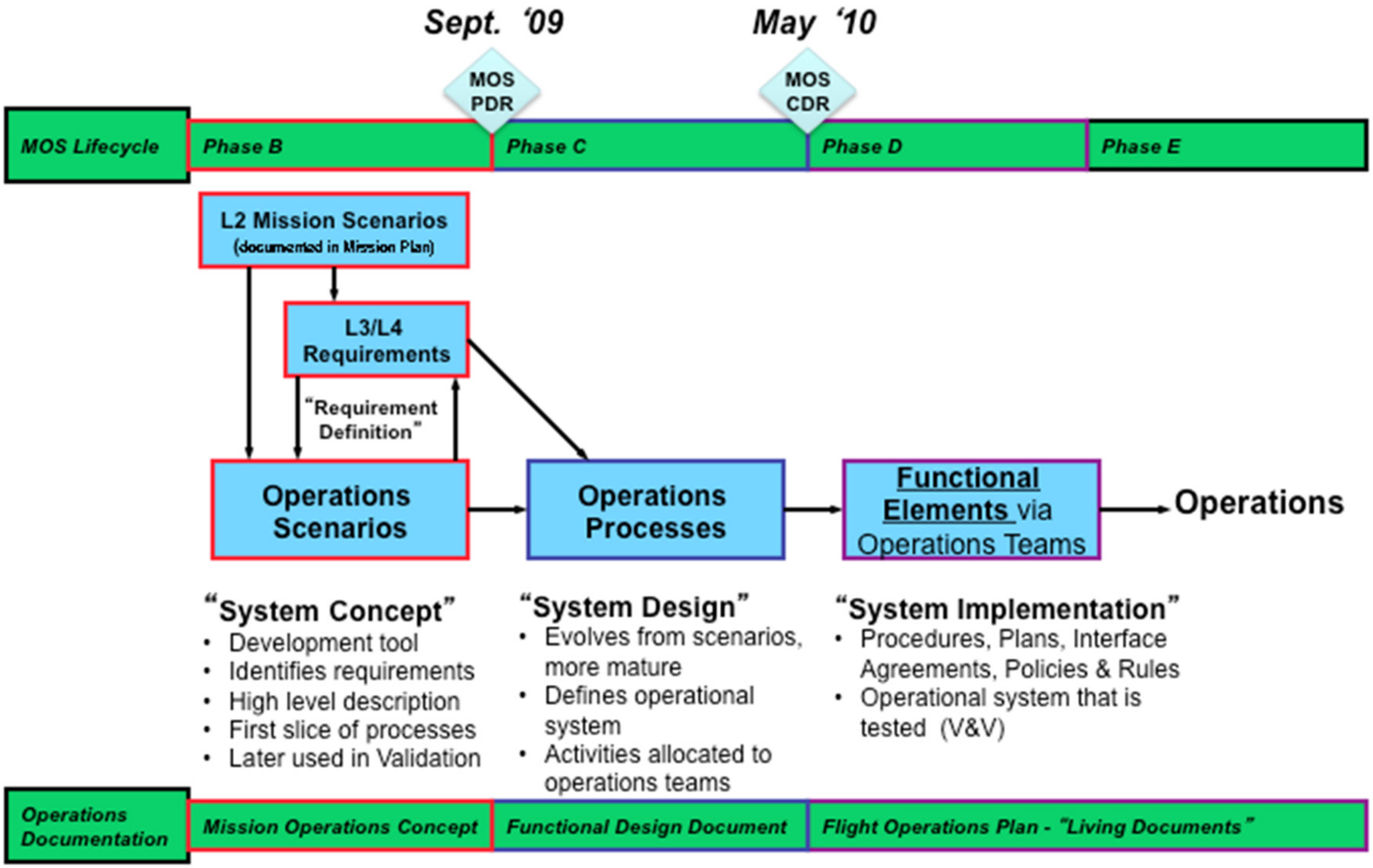
- JPL provides overall mission management, payload operation, multi-mission teams, and Science Data System (SDS)
- Lockheed Martin responsible for spacecraft and real-time operations
- MoonKAM operations led by Sally Ride Science (SRS)





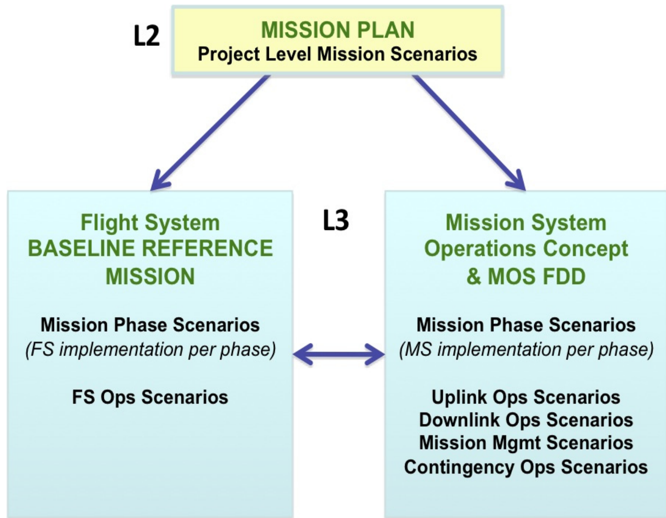
- MOS composed of eight functional elements
  - People, processes, procedures
  - Facilities, hardware, software
- Includes JPL's Multimission Ground Systems and Services (MGSS), and the Deep Space Network (DSN)

MOS Development Process



- MOS development lagged the rest of project: MOS PDR was 11 months after project PDR; and MOS CDR 6 months later than project CDR.

MOS Scenarios Development



- Scenario development occurred at project level (L2) and system level (L3)
  - Mission Plan defined top level timelines and activities
  - Baseline Reference Mission described flight system implementation
  - Operation Concept defined how operations are conducted on the ground.
- 33 operational scenarios were developed spanning all activities required to conduct the GRAIL mission.

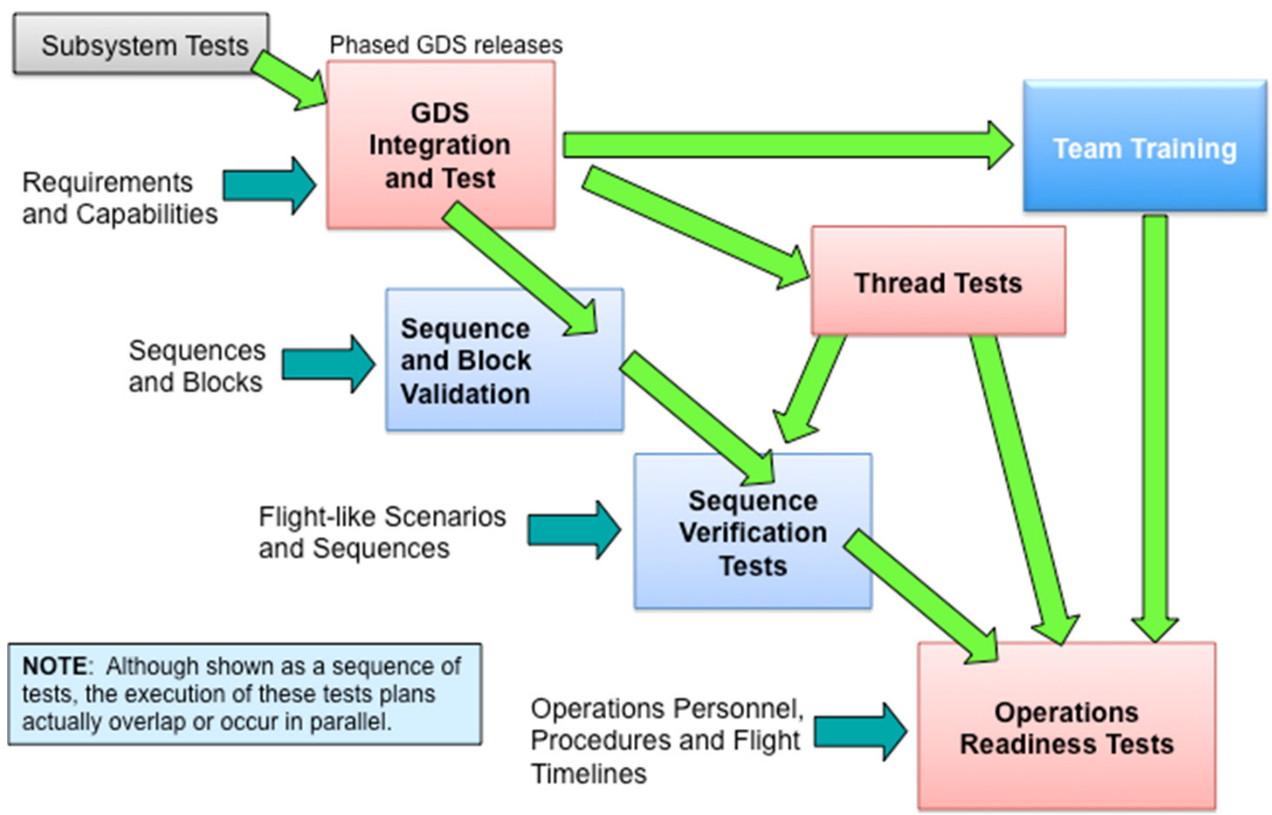
GRAIL Operations Scenarios

Mission Phase	Uplink Operations	Downlink Operations
ATLO	Mission Planning	Mission Monitoring
Launch Operations	Background Sequence Development	Spacecraft Health & Performance Monitoring
TLC Operations	Minisequence Development	Payload Health & Performance Monitoring
LOI Operations	Maneuver Planning	Navigation Trajectory & Flight Path Control
OPR Operations	Real-Time Command Generation	Navigation Trajectory Product
TSF Operations	MoonKAM Commanding	Navigation Real Time Tracking
Science Operations	Commanded Retransmission	Science Data Product Generation
	Command Processing & Radiation	MoonKAM Image Production
	Contingency Operations	**Mission Management**
	Spacecraft Flight Software Update	Anomaly Response
	LGRS Flight Software Update	Status & Coordination
	Recovery from Safing (non-science)	Critical Event Preparation
	Recovery from Safing (science)	Risk Management
		Integrated GDS
		Configuration Management
		Mission Assurance

MOS V&V

- MOS V&V test program featured three key test programs (red) flowing together with other project testing.

- **GDS Integration and Test** verified overall software functionality for each release
- **MOS Thread Test** demonstrated operations functionality, conducted by flight team. MOS products became inputs for other project testing.
- **Operational Readiness Tests** provided final validation of the MOS, demonstrating flight team readiness.



MOS V&V test suite derived from MOS scenario development effort.

MOS Design Tenets

1. Maximize use of Multi-Mission Capabilities	• Multimission Ground Systems and Services (MGSS), NASA's Deep Space Network (DSN), and Lockheed Martin Spacecraft Team. • Minimizing the use of new elements, lowered cost and risk.
2. Consistent Organization between Development and Operations	• Development organization based on the functional elements needed to operate the mission. • Needed experienced development team to transition into operations to support the fast-paced mission timeline
3. Keep Operations Consistent between Orbiters	• Maintain identical operation processes and configuration between the two orbiters. • Change requests applied to both orbiters. • Idiosyncrasies were carefully tracked.
4. Common Maneuver Planning Process throughout Mission	• Each maneuver type had unique design objectives. • Common process was applied to various timelines throughout the mission.
5. Automated Science and E/PO Operations	• Limiting complexity minimized risk of anomalies and interruption of science data collection. • MoonKAM operations had to be non-interactive with higher priority science.
6. MOS Readiness for Full Mission at Launch	• There was no quiet period in the GRAIL timeline to defer any development work.

Key Lessons Learned

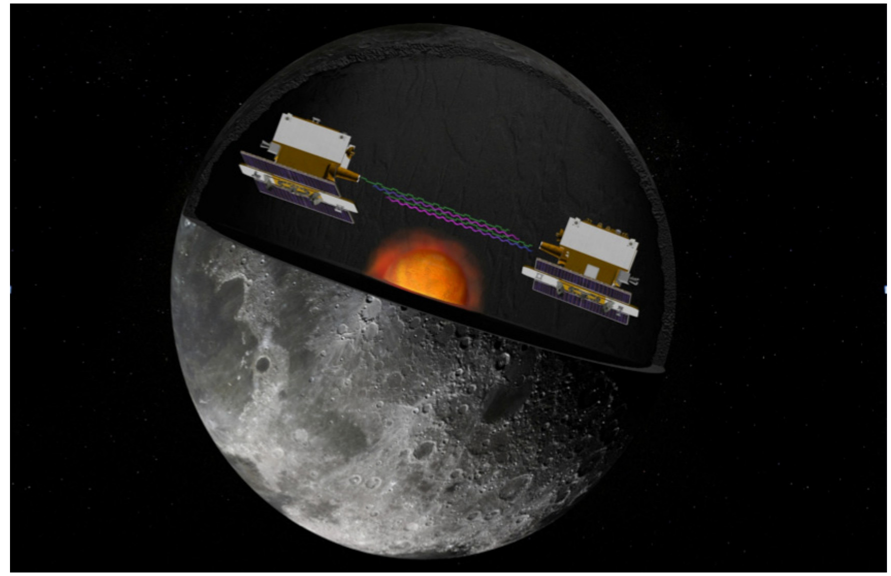
1. Use of heritage multi-mission systems provided significant benefit to operations.
2. MOS delayed development reduced cost, but increased stress in Phase D.
3. Early mission design for maneuver turnaround time underestimated the project's review board risk tolerance.
4. Automation of E/PO MoonKAM operations increased development effort, but paid off during flight.
5. GDS Inheritance review in Phase B was extremely helpful to understanding GDS development scope and effort.
6. MOS Staffing Peer Review was successful in ensuring the right MOS workforce.

Conclusion

- GRAIL mission operations have proceeded smoothly, with only minor anomalies, and the project is well on its way to meeting all prime mission objectives.

- A methodic pre-launch development effort, leveraging use of existing multi-mission operations heritage helped minimize cost and risk.

- Rigorous operational testing prepared the mission operations system and its team for the challenges of the GRAIL mission.



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Affiliation is JPL unless noted.